Efficient computations of wave loads on offshore structures

The present thesis considers numerical computations of fully nonlinear wave impacts on bottom mounted surface piercing circular cylinders at intermediate water depths. The aim of the thesis is to provide new knowledge regarding wave loads on foundations for offshore wind turbines. Hence, the dimensions of the cylinders and the chosen wave parameters were inspired by typical monopile foundations for offshore wind turbines.

The numerical computations are carried out using three numerical solvers. That is, the fully nonlinear Navier-Stokes/VOF solver provided as a part of the open-source CFD-toolbox OpenFoam R, the fully nonlinear potential flow solver OceanWave3D and finally a fully nonlinear domain decomposed solver, which was developed as part of this project. In the domain decomposed solver, the outer wave field is described by the potential flow solver, whereas the inner wave field, in the vicinity of a given structure, is described by the Navier-Stokes/VOF solver.

All numerical models are carefully validated either in terms of convergence by grid refinement or by comparisons to experimental measurements. Special attention is paid to the newly developed domain decomposed solver, which is carefully validated against experimental measurements of regular-, irregular- and multi-directional irregular waves. The ability of the numerical model to accurately reproduce experiments is also investigated.

Wave impacts on a bottom mounted circular cylinder from steep regular waves are presented. Here, the inline forces and the motion of the free surface is described as a function of the non-dimensional wave steepness, the relative water depth, the relative cylinder diameter and a co-existing current. From the computations, higher harmonic forces are determined and compared against the Morison equation and established analytical force formulations accurate to the third order in wave steepness.

The physics related to the strongly nonlinear load phenomena “secondary load cycles” is described and an explanation of the wave load phenomena is provided. To further support the explanation a simple inviscid kinematic model flow is derived.

The discussion of wave impacts on circular cylinders is further extended to uni- and bi-directional phase-focused waves. Here, the influence of the nondimensional wave steepness and wave directionality is discussed. For the steepest wave impacts “secondary load cycles” are observed and the physics of the impact and the mechanisms related to the “secondary load cycle” are discussed and compared to the observations made for regular waves. Additionally, attention is paid to experimental determination of hydrodynamic forces. Significant differences between experimentally measured and computed higher harmonic forces are observed and the differences are explained in terms of the eigenmotion of the test setup. Finally, the application of the domain decomposed solver is discussed in an engineering context. Here, a simple and robust way of identifying forces, which may be inaccurately estimated by the Morison equation, is presented. It is suggested that these impacts are recomputed by the domain decomposed solver.

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